Parallel SAT Solving
To Share or Not To Share

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Theoretical Foundations of Applied SAT Solving

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Parallel Computers

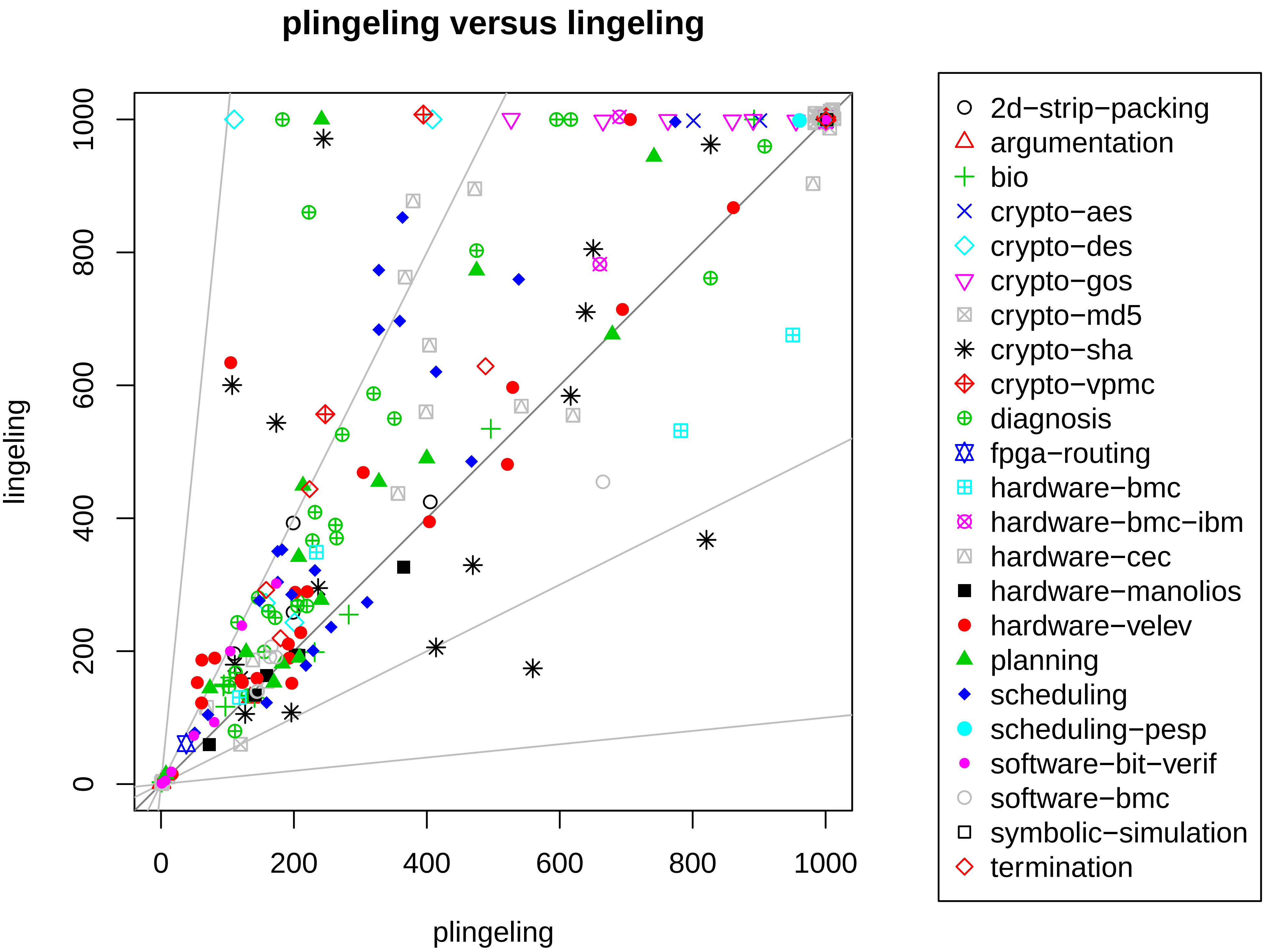
- Multi-Core CPUs
  - CPU frequency scaling stalled but Moore’s Law still holds
    http://ce.cs.jku.at/events/informationsveranstaltung-computational-engineering-slides/ParallelComputing.pdf
  - number of cores per processor is increasing (8-96)
- GPU (graphic processing units)
  - thousands of (dumb) cores
  - focus on data processing (games)
  - 10x-100x more memory througput than CPU (like 5GB/sec vs 200GB/sec)
  - you need to program 1st level cache explicitly (CUDA)
- Cluster
  - also known under the notion of grids
  - cheap, available
- Cloud
  - even more cores
  - scalability in terms of allocating less/more resources
  - slight focus on massive data processing (like map reduce algorithms)

Challenge

- we want to solve even harder problem than those we can solve today
- we do have (easy) access to parallel computers
- how to parallelize SAT?
- how to get **speed-up** (sequential divided by parallel wall clock time)
  - current model in HPC (high performance computing): hero programmer
  - fight between correctness and efficiency (lock vs no-lock)
- different strategies for different parallel computers

Why am I standing here?

- developped parallel solvers Plingeling, Treengeling
  - Plingeling
    - portfolio solver (makes use of the 321 options of Lingeling)
    - technically it only uses call backs from the core Lingeling library
    - sharing of units + equivalences + short clauses
  - Treengeling
    - (concurrent) cube & conquer solver
    - portfolio component sharing of units and refuted cubes
- Cube & Conquer [HeuleKullmannWieringaBiere'11]
  - use look-ahead SAT solver to produce cubes
  - solve those cubes in parallel with CDCL
- won several first places in recent competitions
  - next slide: parallel application track 2014 with time-out 1000 sec (4 cores)
  - http://satcompetition.org/edacc/sc14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lingeling
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argumentation
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crypto−aes
crypto−des
crypto−gos
crypto−md5
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crypto−vpmc
diagnosis
fpga−routing
hardware−bmc
hardware−bmc−ibm
hardware−cec
hardware−manolios
hardware−velev
planning
scheduling
scheduling−pesp
software−bit−verif
software−bmc
symbolic−simulation
termination

Levels of Parallelization (in SAT Solving)

- Service Level [Cloud, Cluster, Multi-Core]
  - cloud/cluster provider offers compute resources specialized to SAT/SMT/MC...?
- Application Level [Cluster, Multi-Core]
  - solve and schedule multiple similar or related problems in parallel
  - in HW model checking quite common (one RTL model + dozens of properties)
- Portfolio Level [Multi-Core maybe Cluster]
  - run different solvers (or solver configuration) in parallel
  - share information (clauses, units, equivalences, ...)
- Engine Level [Multi-Core]
  - use different algorithms which support each other, e.g., pre/inprocessing
  - originally sequential, can (easily?) be parallelized, results shared
- Search Level [Cloud, Cluster, Multi-Core]
  - search space splitting, e.g., guiding path, cube & conquer, sharing is hard
- Implementation Level [Multi-Core, GPUs]
  - parallel BCP [...], use parallel thread for clause minimization [Wieringa...]
  - parallelize CDCL analyze and BCP [unpublished but also does not really work]

Parallel SAT Solving

- dominating approach: portfolio with clause sharing
  - *ManySAT*, *Plingeling*, *Penelope*, ...
  - successful in the application track of the competition
  - portfolio already gives substantial speed-up
  - clause sharing of "good" clauses gives another boost
- search space splitting
  - originally used on clusters / grids
    - guiding path principle [ZhangBonacinaHsiang'96]
    - revisited and extended recently [HyvärinenJunttilaNiemelä'10]
  - can be combined with look-ahead
    - Cube & Conquer approach [HeuleKullmannWieringaBiere'11]
    - works well on multi-core as well
    - Treengeling won parallel combinatorial track in SAT Competition 2013/14
- how to merge these two approaches?
- scalability for many cores and larger clusters / grids / cloud

Data Flow Algorithms for SAT

- most paradigms for SAT solving are control-dominated:
  - such as variants of CDCL, WalkSAT, or Look-Ahead based algorithms
  - hard to port to highly parallel computing architectures like:
    - bit-parallel operations on streaming units (SSE, AVX ops with 128 bit - 256 bit)
    - multi-core systems with say 96 or even more cores
    - clusters / grid / clouds with 128 - 100000 cores
    - GPUs with more than 2000 cores
  - control flow dominated algorithms have a hard to time to achieve memory locality
- conjecture is that data-flow orientation allows memory locality
  - challenge is to come up with SAT algorithms organized around data-flow
  - find other ways to change algorithms / machines to become more “local”
- our experiences with bit-parallel SAT and GPU’s are rather negative
  - only focused on preprocessing sofar
  - positive effect for few crafted instances, usually way slower

    see Master thesis by Robert Aistleitner

Conclusion

- parallelize SAT for solving harder problems
- parallelize SAT to econmically make use of available HW
- we are just at the beginning of making parallel SAT work
- talk by Asish at Banff: proof span = computational span = parallelizability
- I think we need totally new algorithms (which is quite exiting)
- just got 4 years of funding for parallel SAT solving (Post-Doc seeked)

see also Dissertation Norbert Manthey, particularly, pages 225ff